ASU Sound & Vibration Lab

Faculty of Engineering
Ain Shams University

Acoustics

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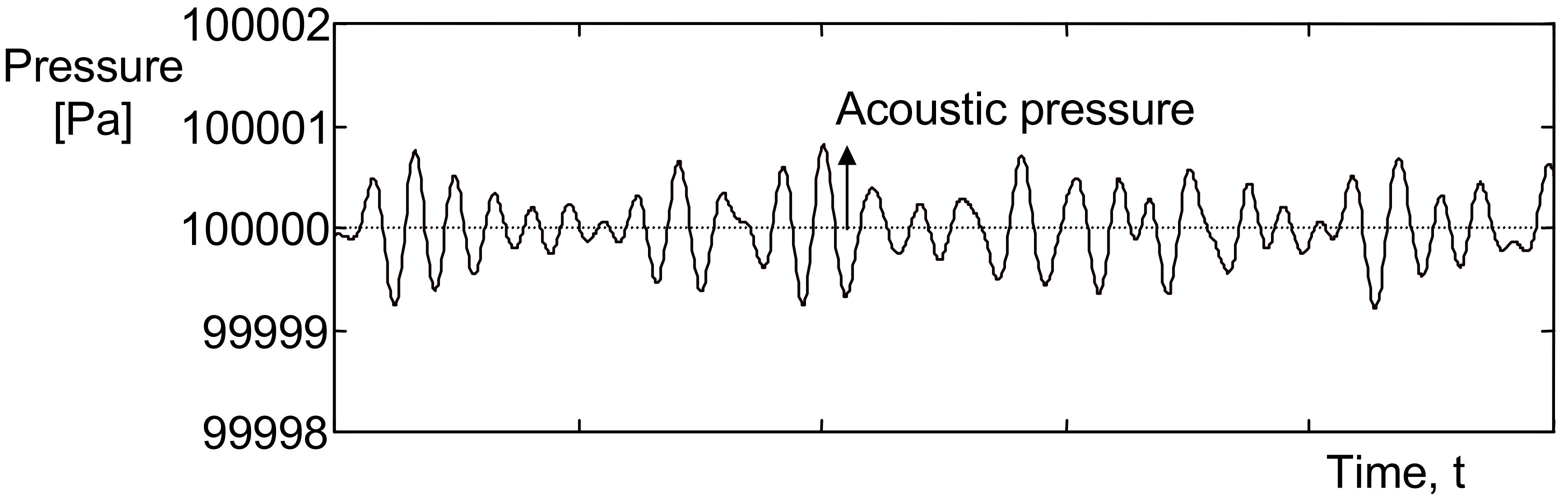
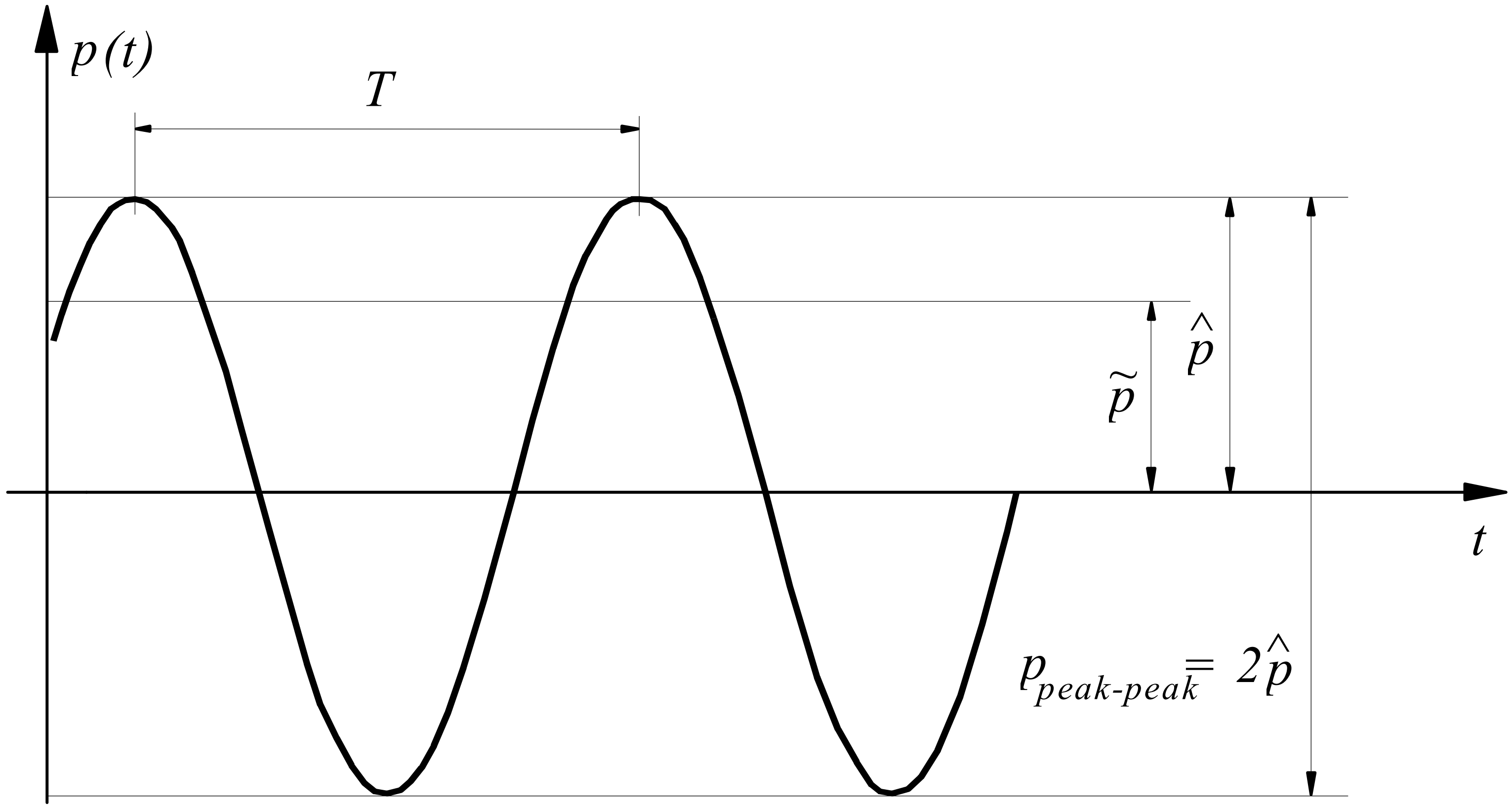
#3: Acoustical Quantities and Wave phenomena



Average pressure is equal to atmospheric pressure.

Small fluctuations around this value are acoustic pressure.

Peak, mean, peak-peak, RMS, and Frequency



Definitions

$$p(t) = \sin(\omega t + \varphi)$$

Time averaged mean value

$$\overline{p} = \frac{1}{T}\int_0^T p(t)dt$$

RMS value

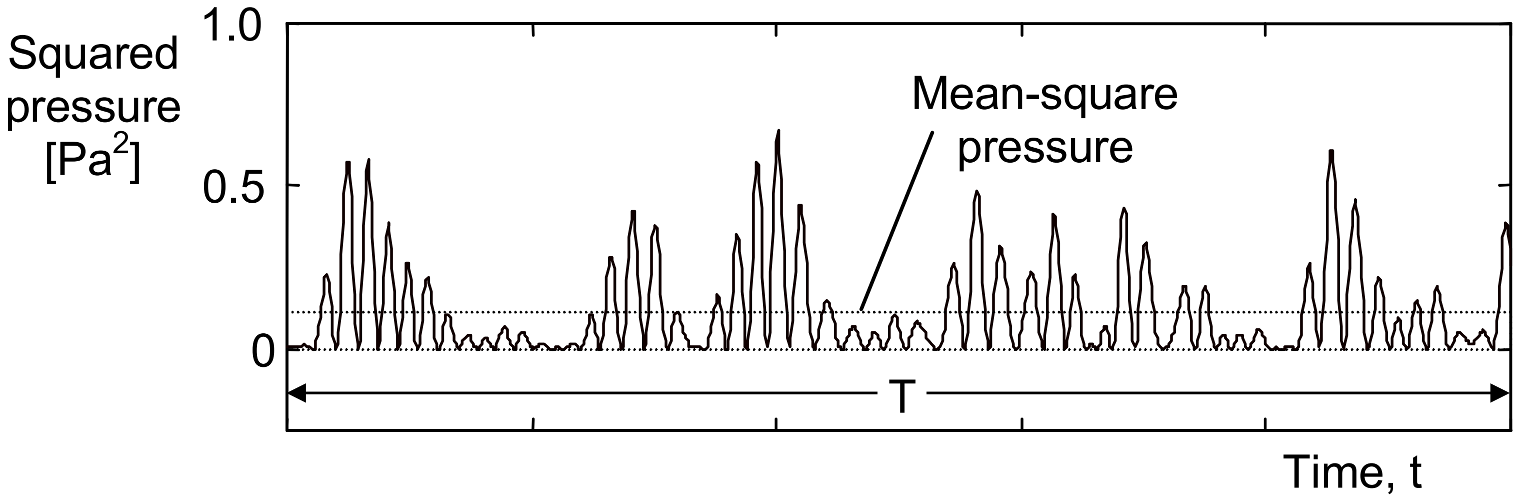
$$\tilde{p} = \sqrt{\frac{1}{T}\int_0^T p^2(t)dt}$$

Peak Factor or Crest Factor

$$TF = \hat{p}/\tilde{p}$$

For a harmonic signal

$$\tilde{p} = \hat{p}/\sqrt{2}$$



Average the *squared* acoustic pressure (mean-square):

$$\overline{p^2} = \frac{1}{T} \int_{t_1}^{t_1+T} p^2(t)\, dt$$

Square root of this is the root mean square (rms) pressure.

It can depend strongly on the averaging time.

RANGE OF SOUND AMPLTIDES

- The large range of pressure amplitudes corresponds to a much smaller range of dB values:
  - threshold of hearing at 1000 Hz: 2×10^{-5} Pa – **0 dB**
  - rustling leaves: 2×10^{-4} Pa – **20 dB**
  - conversation: 0.01 Pa – **54 dB**
  - noise inside a vehicle at idle: 0.1 Pa – **74 dB**
  - noise inside a vehicle at 120 km/h: 1 Pa – **94 dB**
  - threshold of feeling: 20 Pa – **120 dB**
  - threshold of pain: 200 Pa – **140 dB**

Sound Power and Sound Intensity

SOUND POWER AND INTENSITY

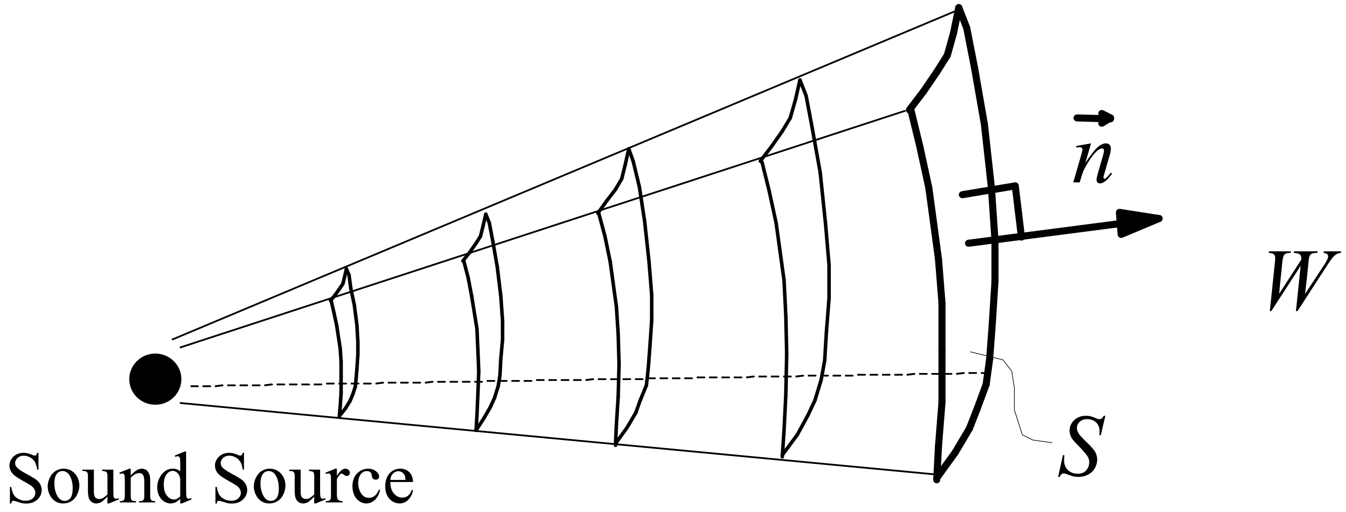
Sound waves transmit energy. The total sound energy emitted by a source per second is its sound power, ***W*** **(in Watts).**

The sound intensity **is the sound power per unit area** $I = W/A$.

Sound Power

$$W(\vec{r},t) = \int_S p(\vec{r},t)\vec{u}(\vec{r},t)\vec{n}dS$$

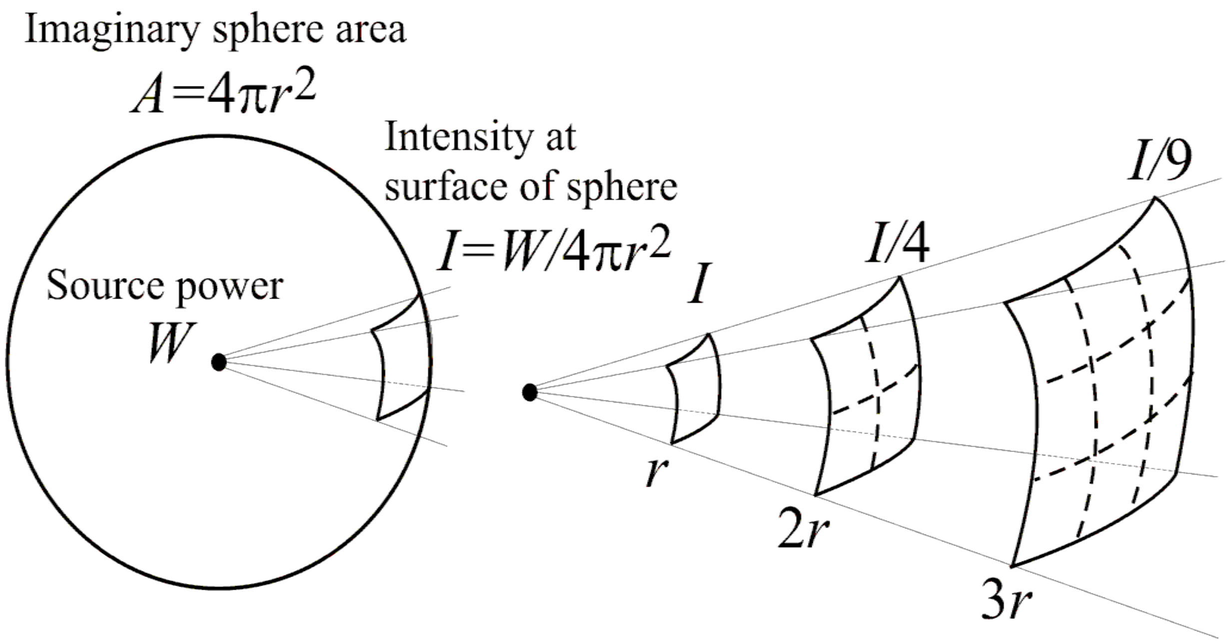
Force x velocity



SOUND POWER AND INTENSITY

For a point source the intensity reduces with the square of the distance ("inverse square law").

Far from the source the sound pressure is proportional to the square root of intensity, so $p \propto 1/r$



SOUND POWER AND INTENSITY LEVEL

Sound power level:

$$L_W = 10\log_{10}\left(\frac{W}{W_{ref}}\right)$$

- W_{ref} is usually 10^{-12} W. Then we write: **dB re 10^{-12} W**.

Sound intensity level:

$$L_I = 10\log_{10}\left(\frac{I}{I_{ref}}\right)$$

- I_{ref} is usually 10^{-12} W/m^2. Then we write: **dB re 10^{-12} W/m^2**.

Sound Pressure Level (SPL)

Time averaged power values are proportional to the squared rms amplitudes of the filed variables (pressure, particle velocity)

$$L_p = 10 \cdot \log \frac{\tilde{p}^2}{p_{ref}^2}$$

- P_{ref} is usually 2×10^{-5} Pa Then we write: **dB re 2×10^{-5} Pa**.

Vibration Velocity Level

$$L_v = 10 \cdot \log \frac{\tilde{v}^2}{v_{ref}^2}$$

- V_{ref} is usually 10^{-9} m/s Then we write: **dB re 10^{-9} m/s**.

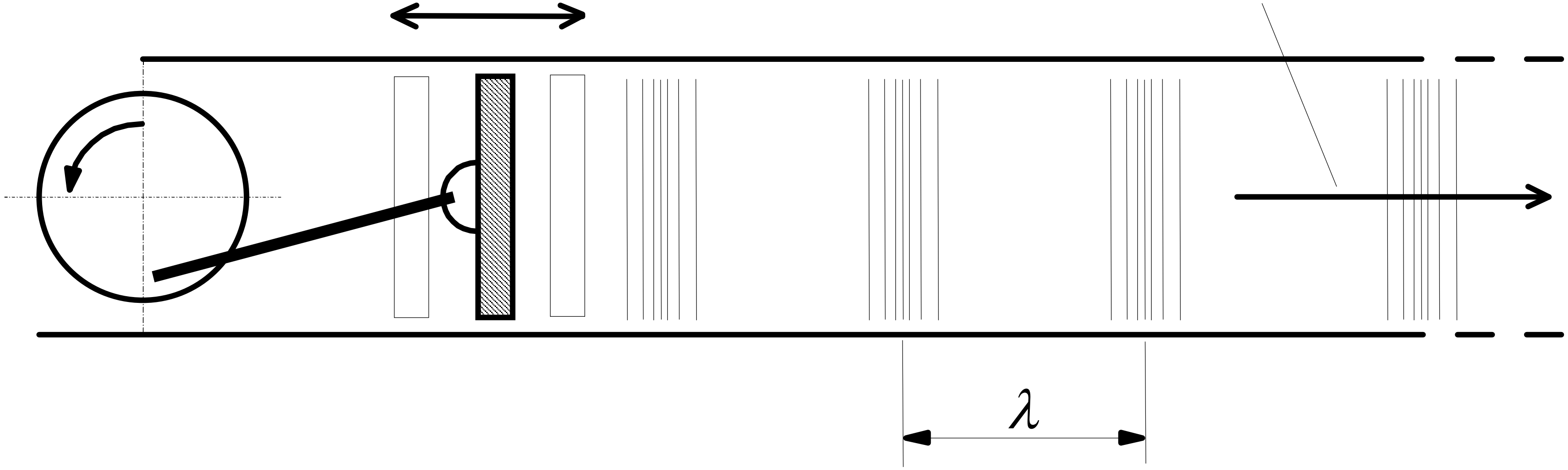
Longitudinal Waves:
Plane – Spherical – Cylindrical

Plane Waves

Harmonic vibrational velocity

$v(t) = \hat{v} \cdot \sin(2\pi f t)$

Direction of Propagation



Plane Waves

$$p(x,t) = \rho_0 c u_x (x,t)$$

$$\overline{W} = \frac{1}{T}\int_0^T W(t)dt$$

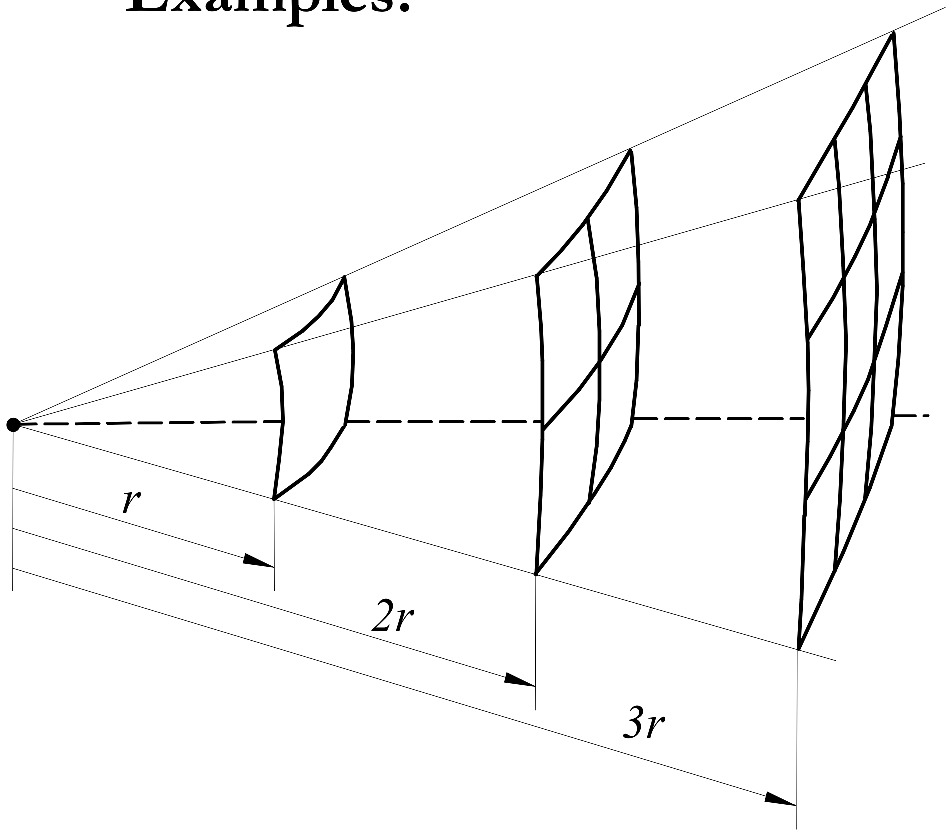
$$\overline{W} = \frac{1}{T}\int_0^T \frac{p^2(x,t)S}{\rho_0 c}dt$$

$$\overline{W} = \tilde{p}^2 S \big/ \rho_0 c$$

$$\bar{I}_x = \overline{W} \big/ S = \tilde{p}^2 \big/ \rho_0 c$$

Spherical Waves

Examples?



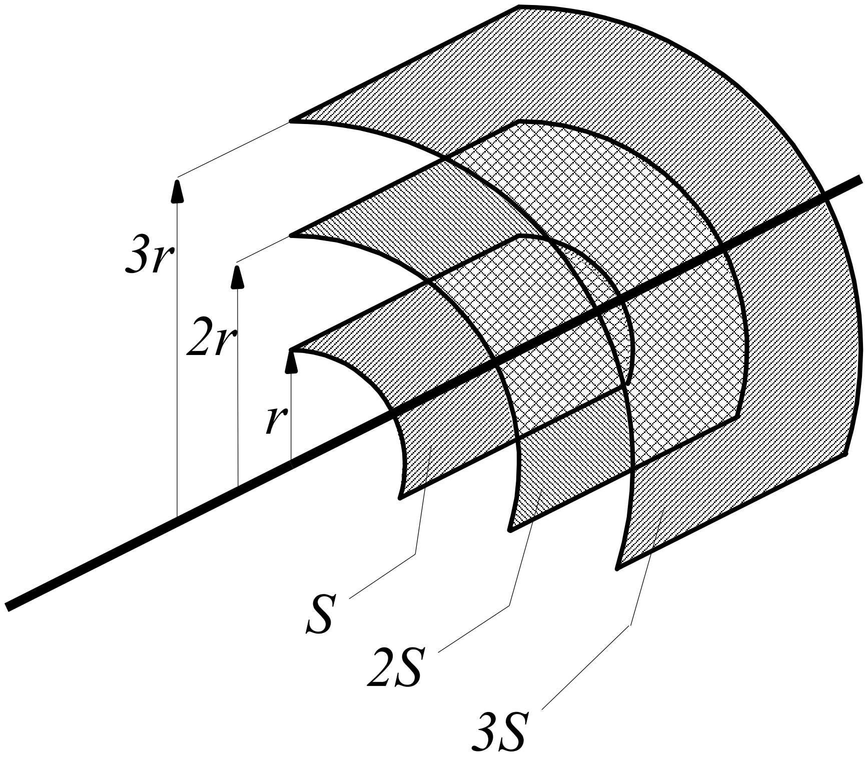
$$\bar{I}_r = \overline{W} / 4\pi r^2$$

$$\tilde{p} = \sqrt{\rho_0 c \overline{W} / 4\pi\, r^2}$$

Plane waves at r > λ / 3

Cylindrical Waves

Examples?



$$\bar{I}_r = \overline{W}'/2\pi\, r$$

Diffraction

Diffraction

In all types of wave propagation

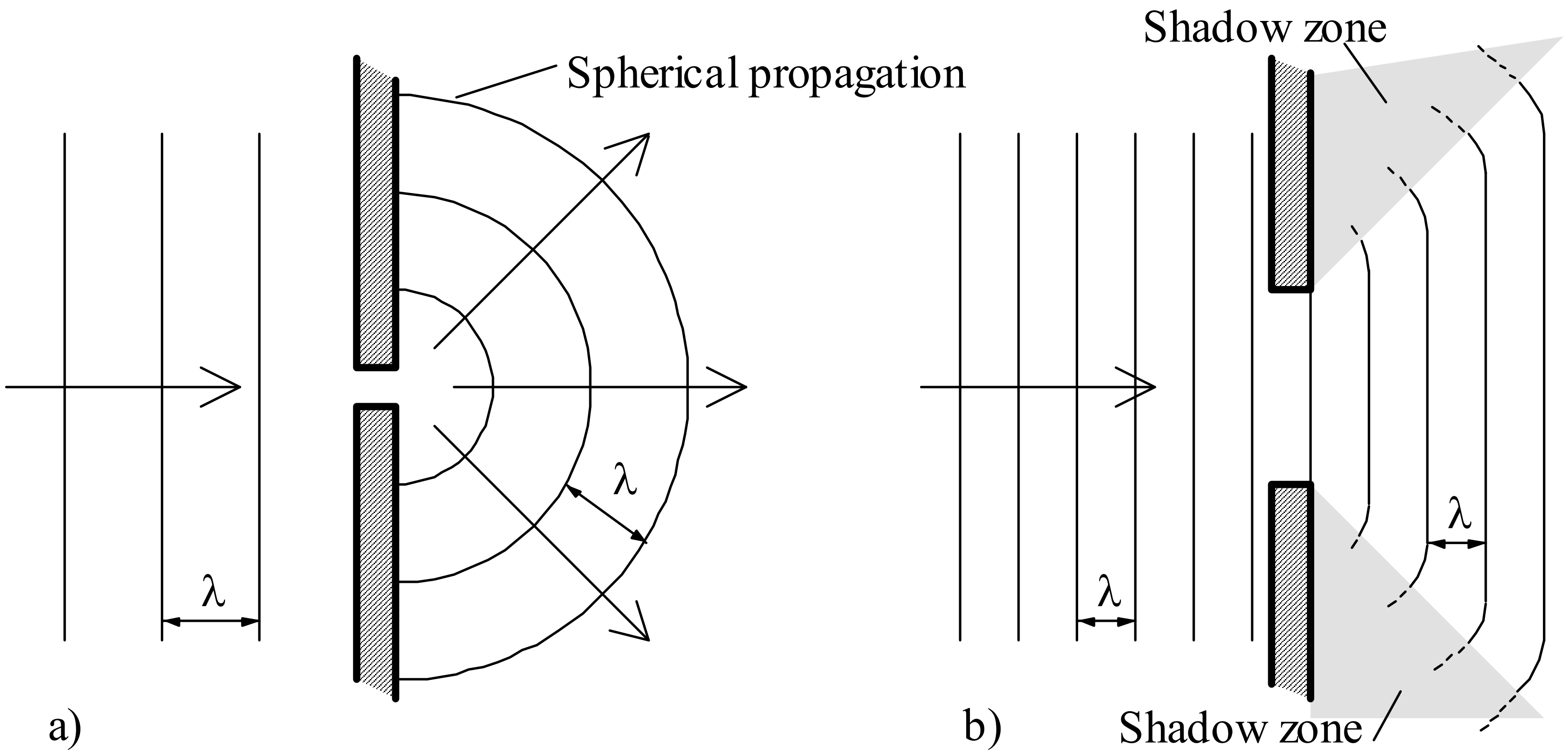
Depends on relative size of obstacle and wavelength of wave.

Light wavelength is approx 10^{-7}m

Speech wavelength is approx 1 m

Oooooo (250 Hz)

Sssssss (6000 Hz)

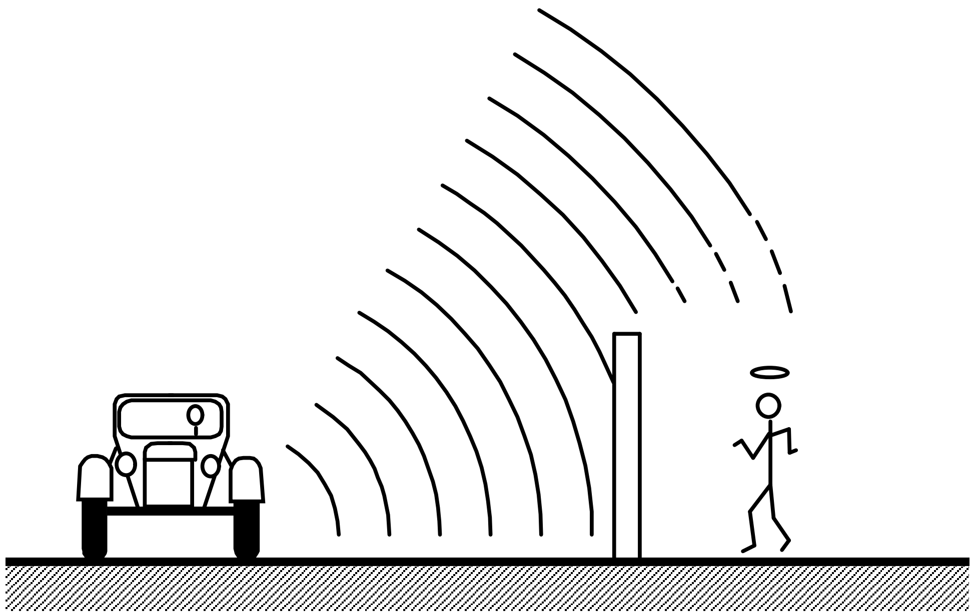

Spherical propagation
λ
λ
a)
Shadow zone
λ
λ
b)
Shadow zone

Sound Barriers for Highways

Highways – 70 km/hr – tyre/road noise

Effective in low frequency or high frequency range?

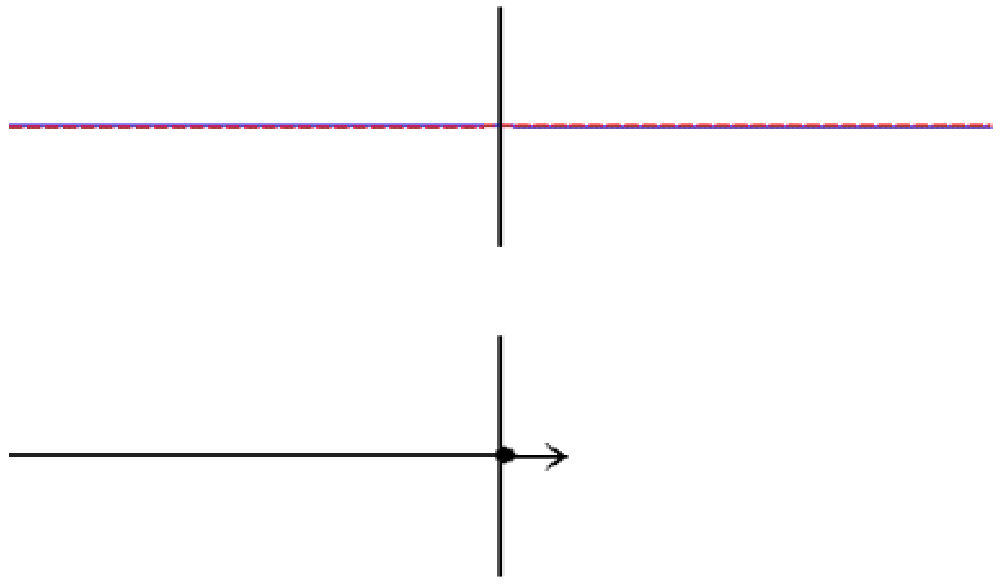
Most effective if barrier is close to source or receiver?



Standing Waves

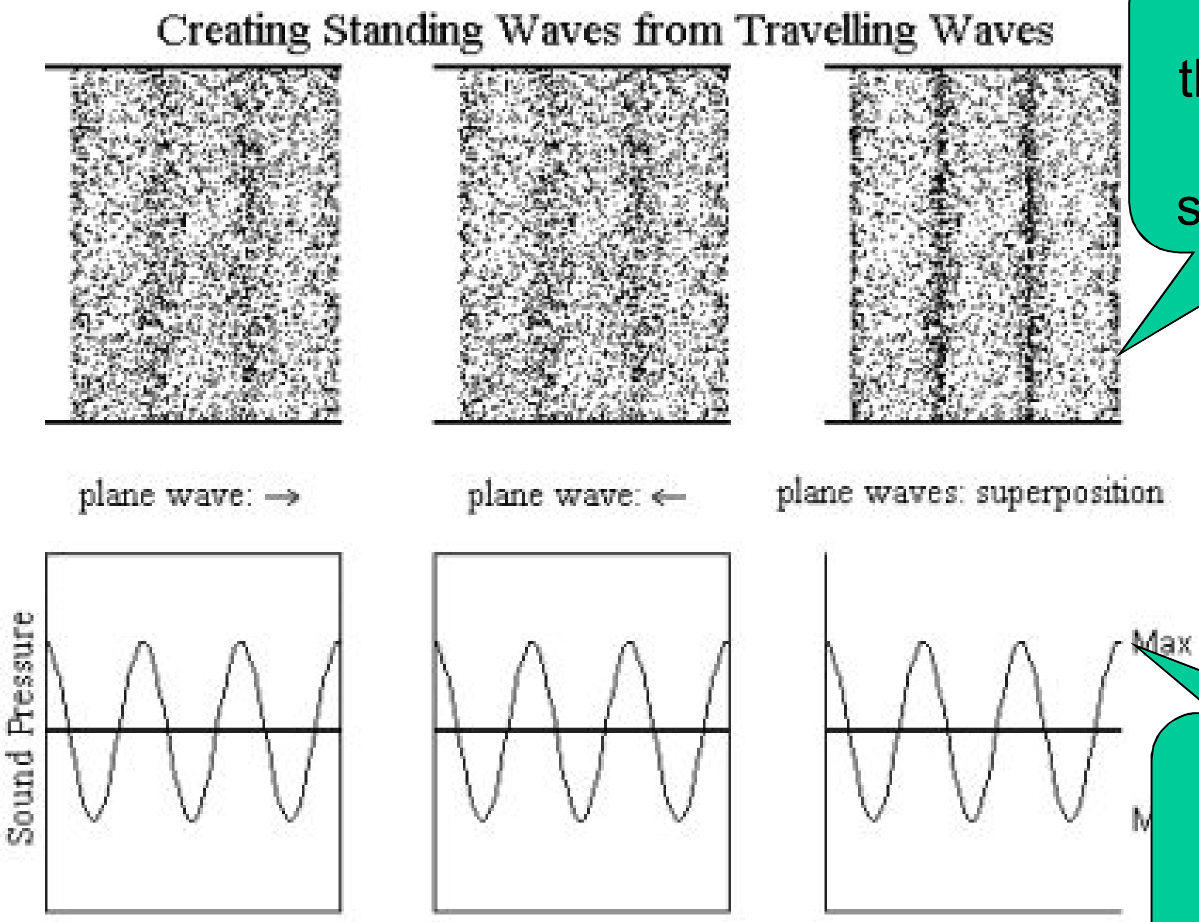
WAVE REFLECTION

- When waves meet a boundary they are reflected.
- Example of a wave in a string: actual string motion made up of 'incident wave' and 'reflected wave'.



STANDING WAVES

- Standing waves may be created from two waves of equal amplitude and frequency travelling in opposite directions (e.g. reflections between two hard walls).

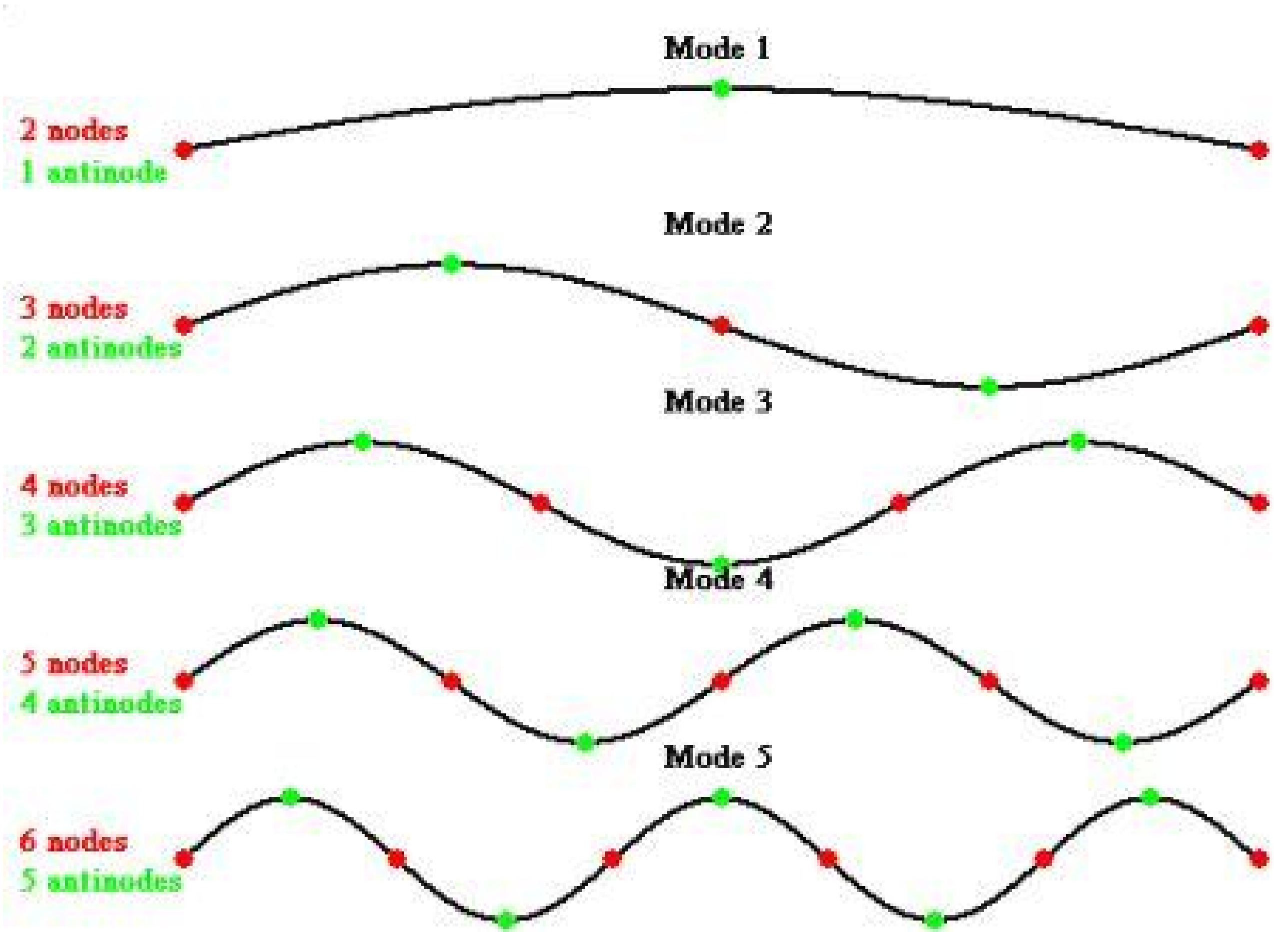


Note that the particles are stationary at the edges

But the pressure amplitude is maximum

STANDING WAVES

- Examples of standing waves in a string.
- Number of nodal points / anti-nodes increases with frequency.



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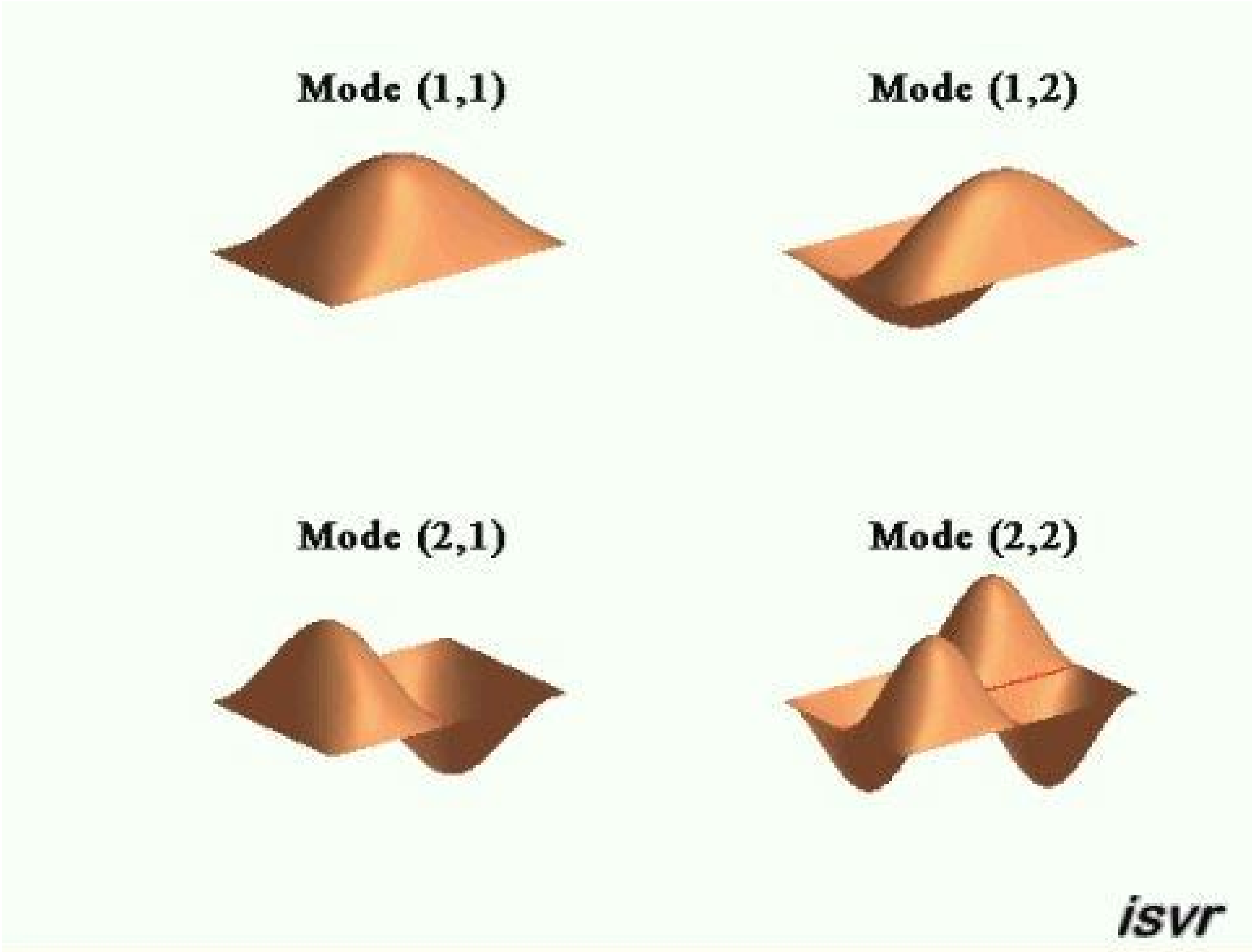
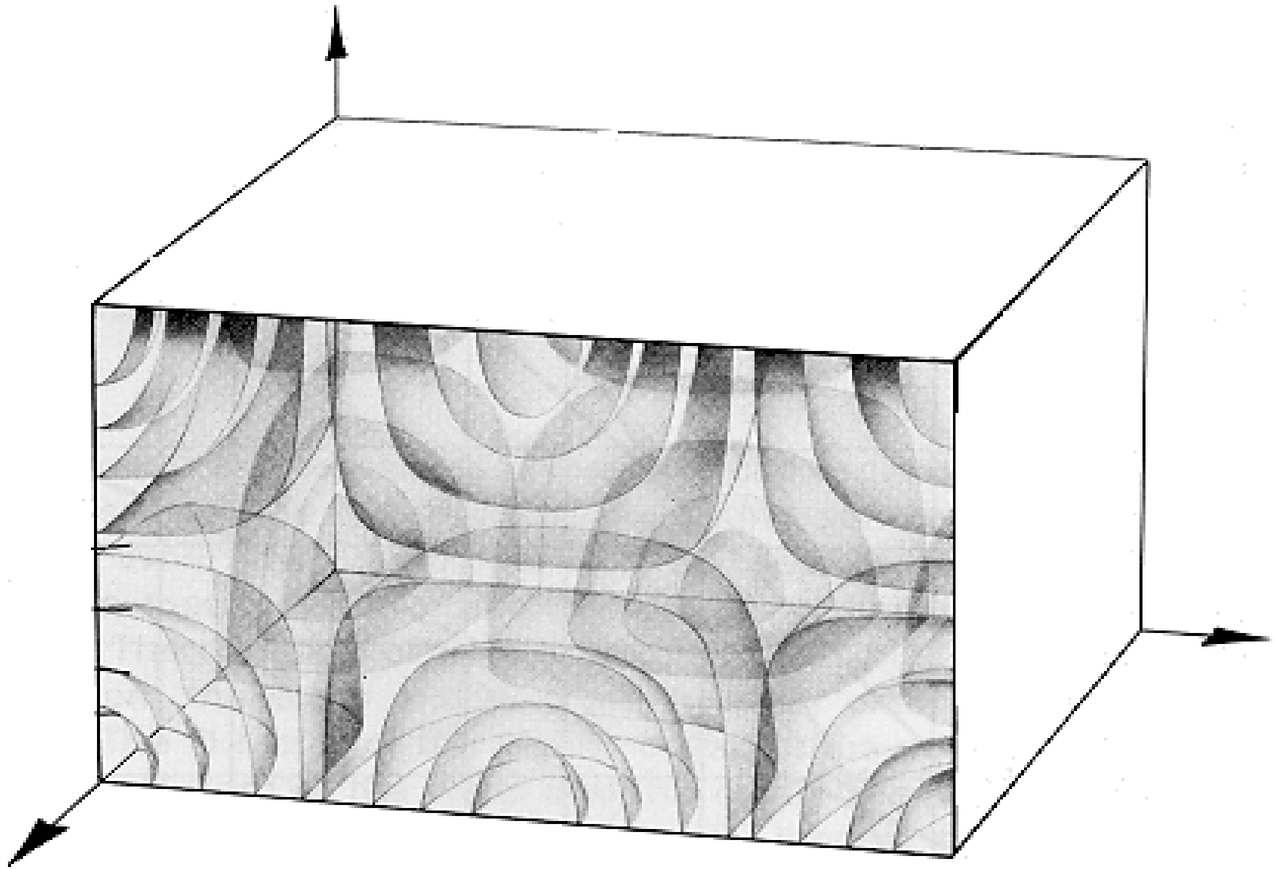
STANDING WAVES

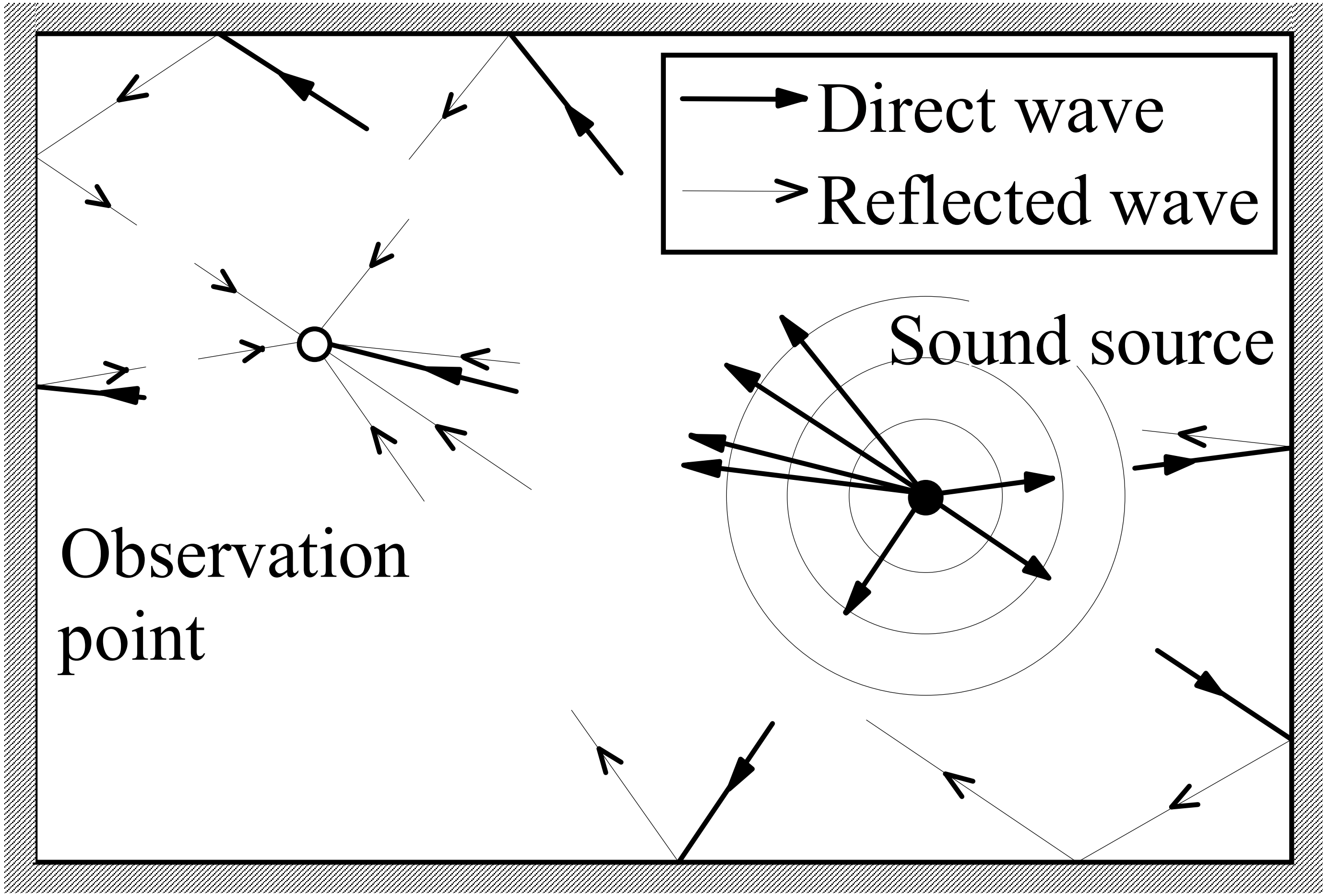
- Examples of standing waves in a membrane.
- Modes defined by number of anti-nodal lines in each direction.



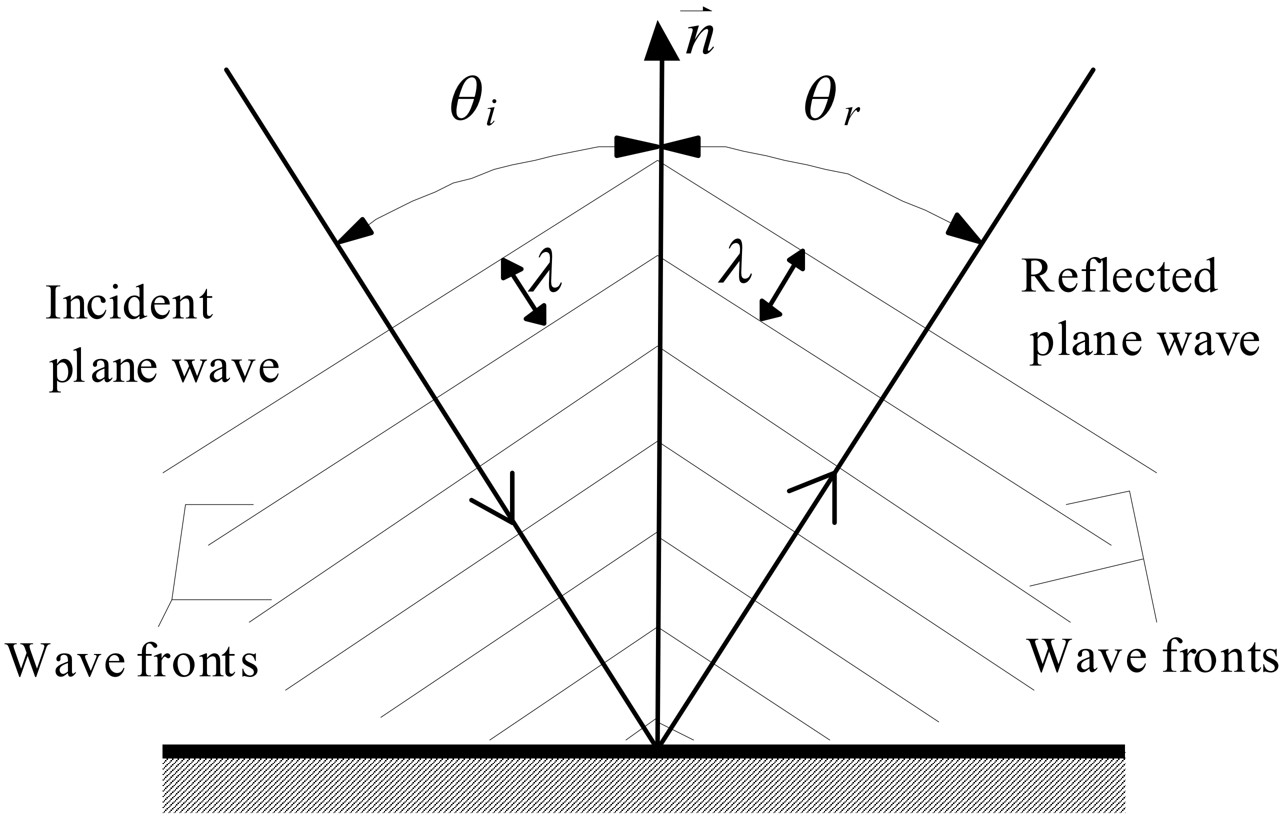
Sound in Closed Spaces

Room Modes

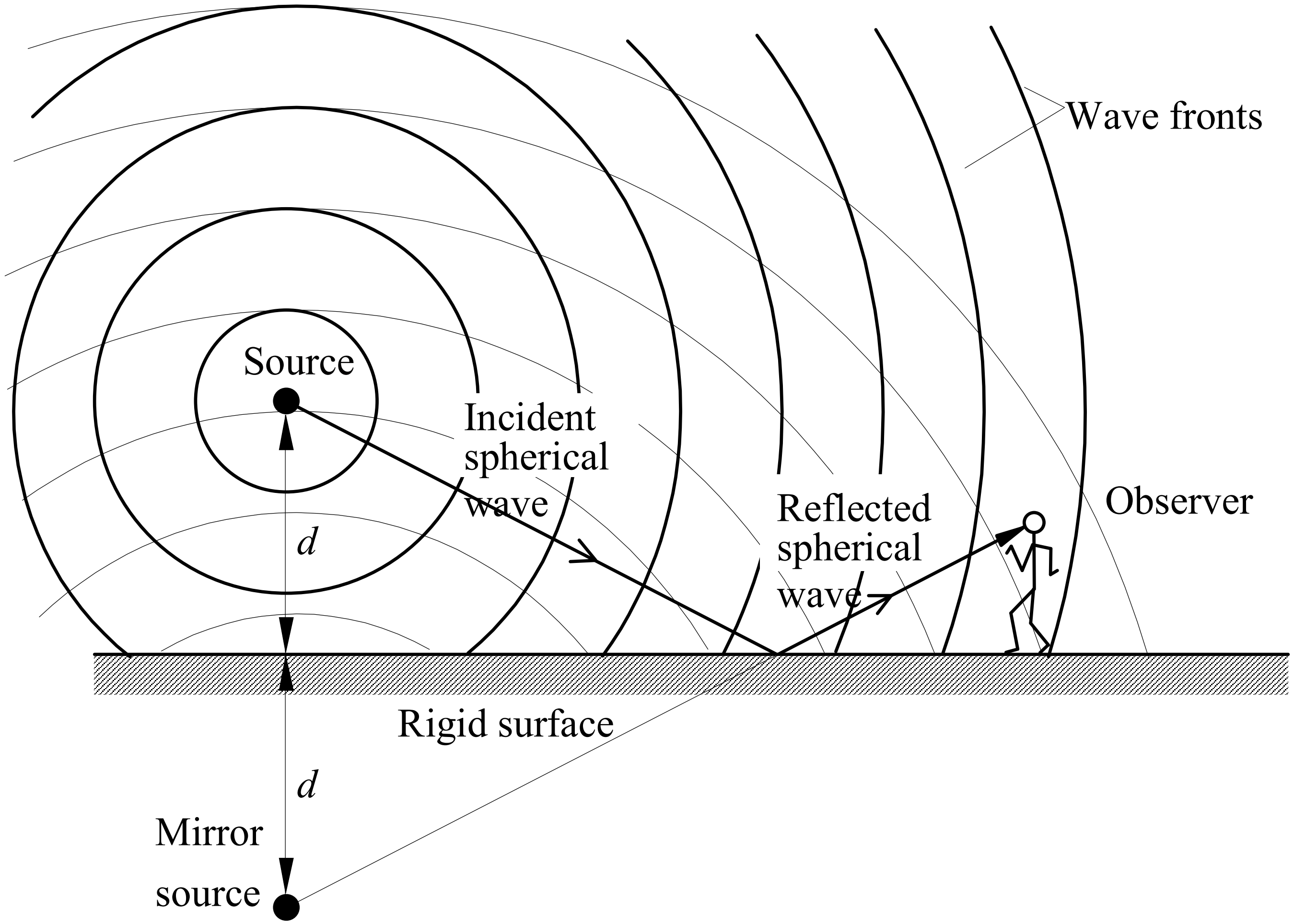



Direct wave
Reflected wave
Sound source
Observation point

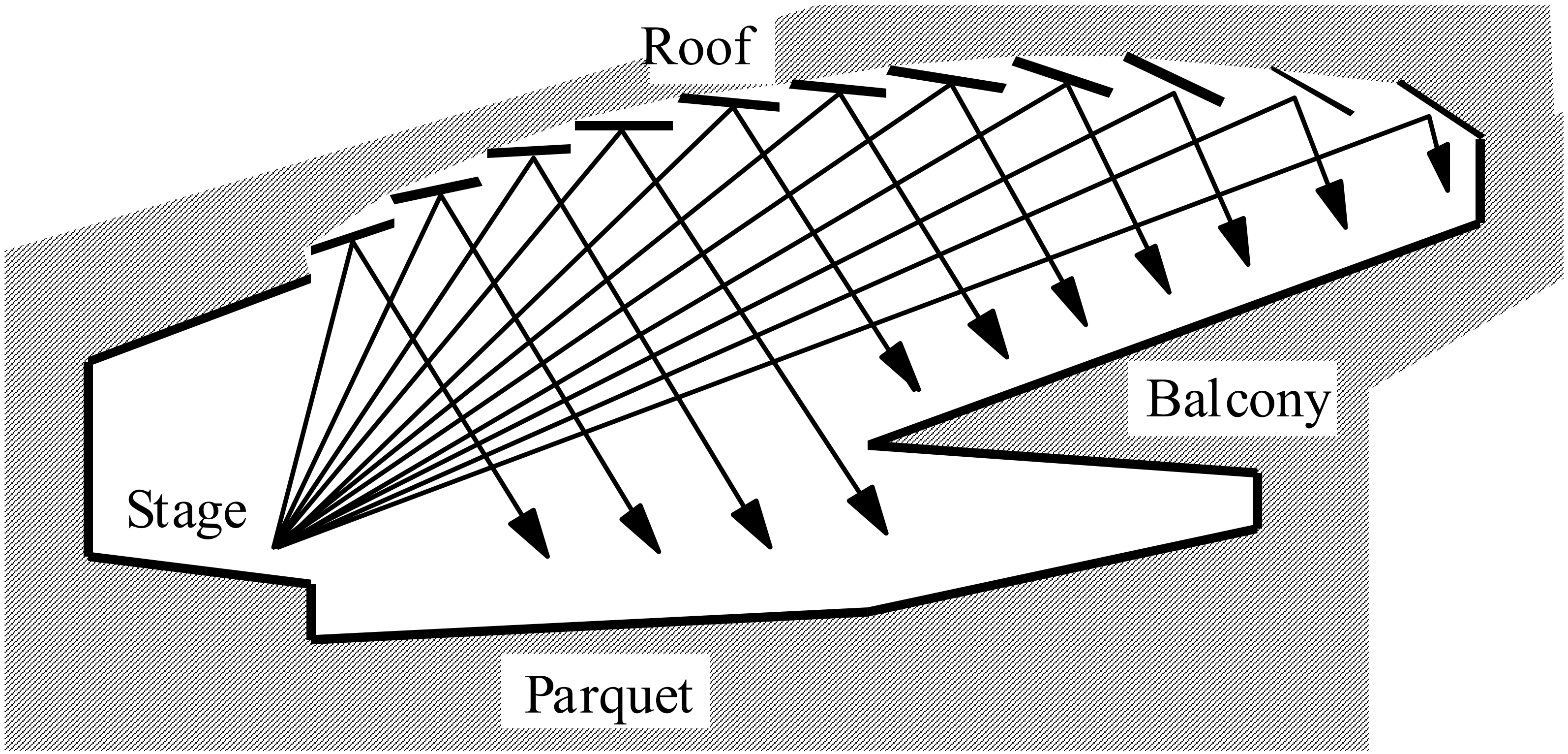
Reflection


$\vec{n}$
θ_i
θ_r
λ
λ
Incident plane wave
Reflected plane wave
Wave fronts
Wave fronts

Ground Reflection



Room Reflections



No Focus – No Shadow Zone

Room Acoustics